Free-Space Optical Communications: Attenuation in Clouds and Downlink Availability

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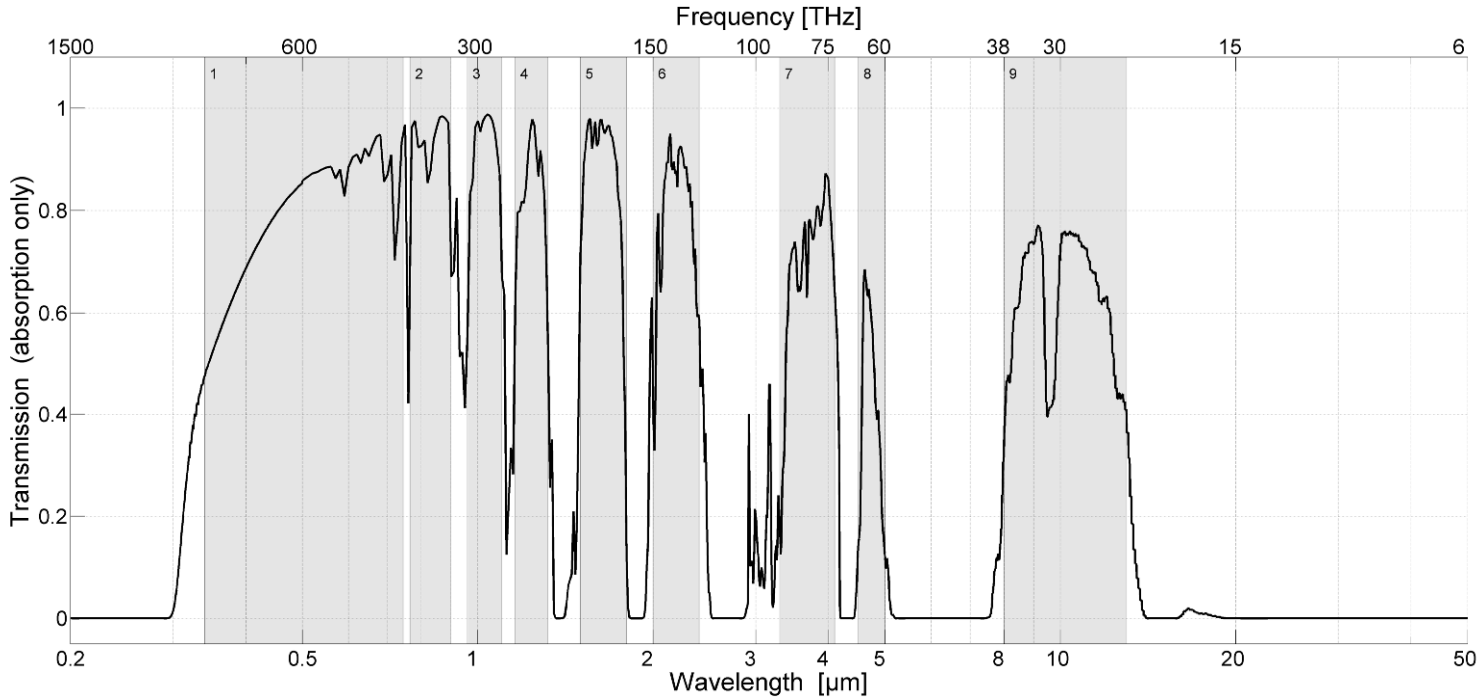
Motivation: Search for Cloud Propagating Wavelengths

- Wavelengths must lie inside an atmospheric window
- Above 20µm no feasible wavelength can be found due to absorption bands of H_2O
- In the VIS and NIR clouds are totally opaque



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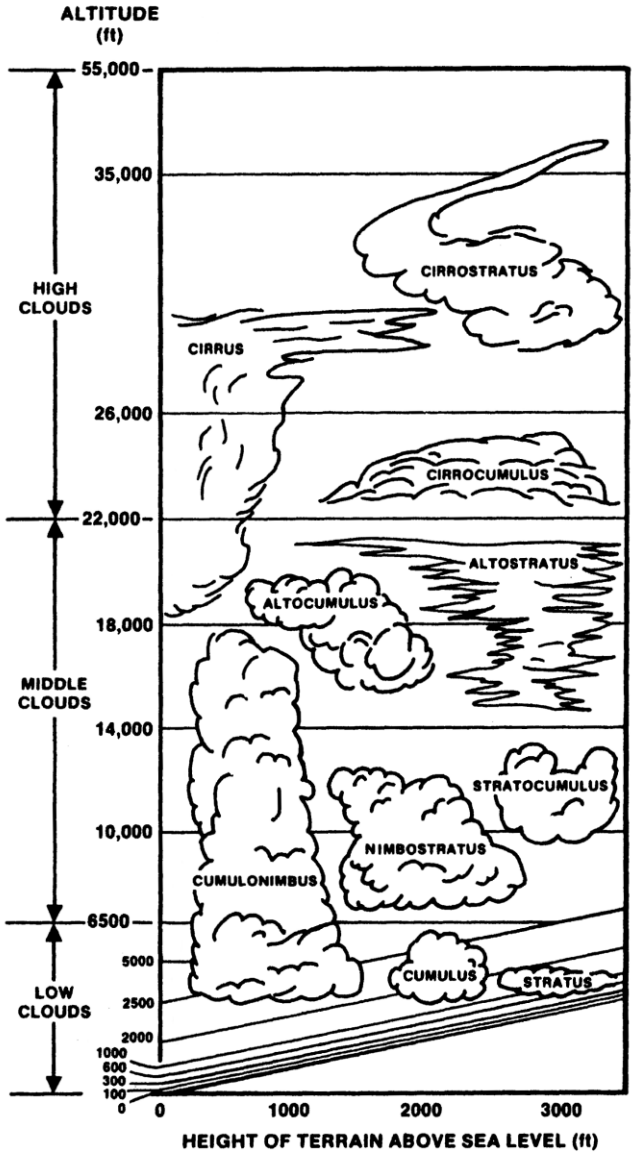
Attenuation in Clouds

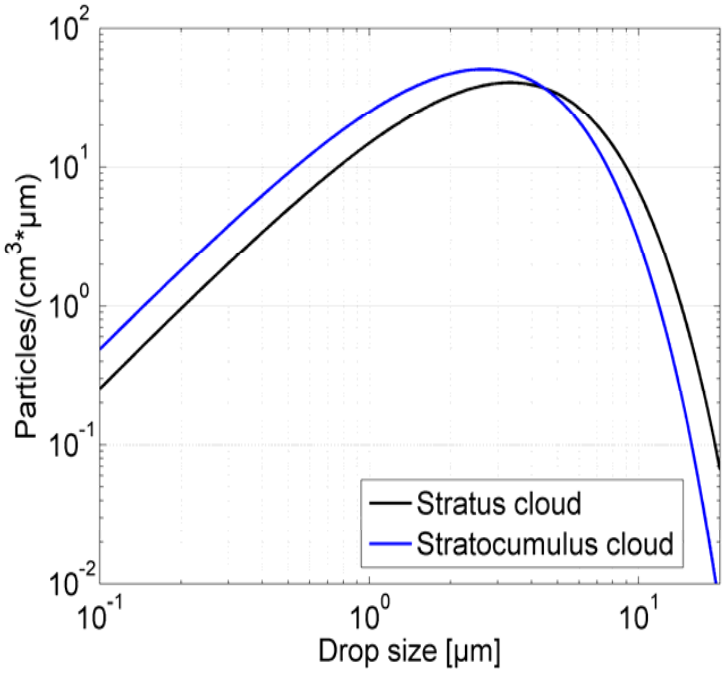
- Variable water content
- Particle size and shape
- Variable thickness

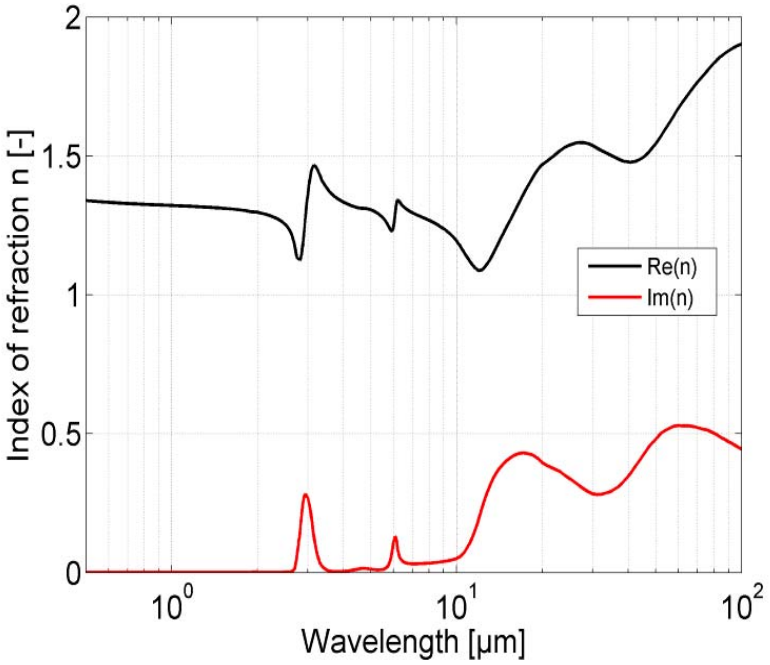
Cloud type	Base height [km]	Vertical extent [km]	Water content [g/m3]
Stratus	0.1 – 0.7	0.2 – 0.8	0.29
Stratocumulus	0.6 – 1.5	0.2 – 0.8	0.15
Nimbostratus	0.1 – 1.0	2 - 3	0.65
Altostratus	2 – 6	0.2 - 2	0.41
Cumulus	0.5 – 1.0	0.5 – 5	1.00
Cirrus	6 – 10	1.0 – 2.5	0.064



Attenuation in Clouds

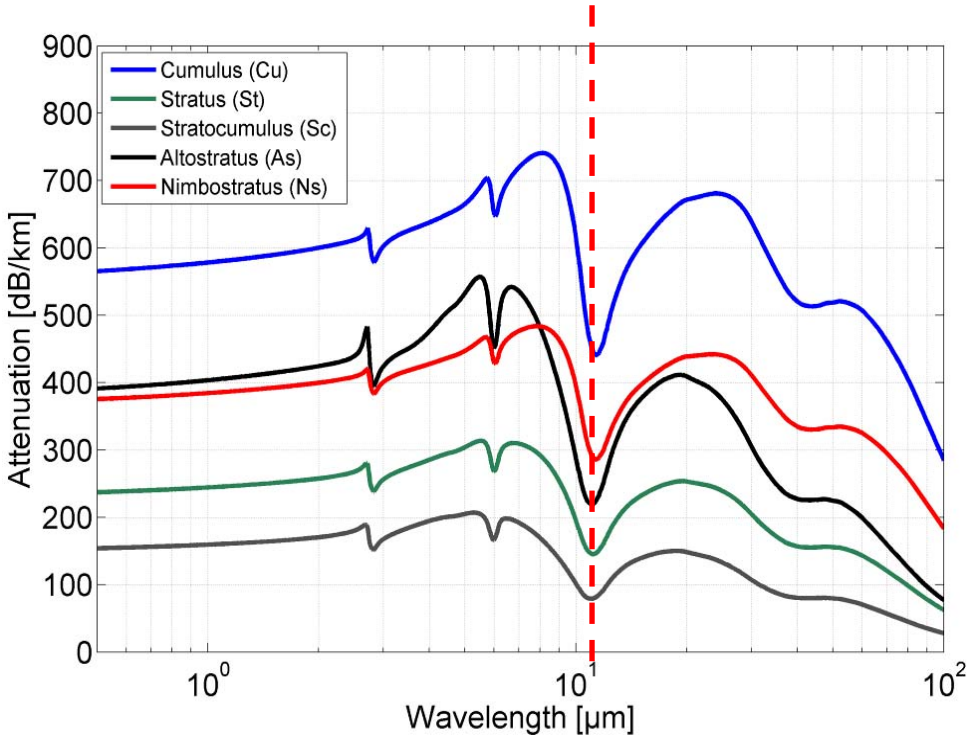
- Particle size distribution and complex index of refraction → cloud model
- The Mie calculation results in extinction coefficient of the cloud

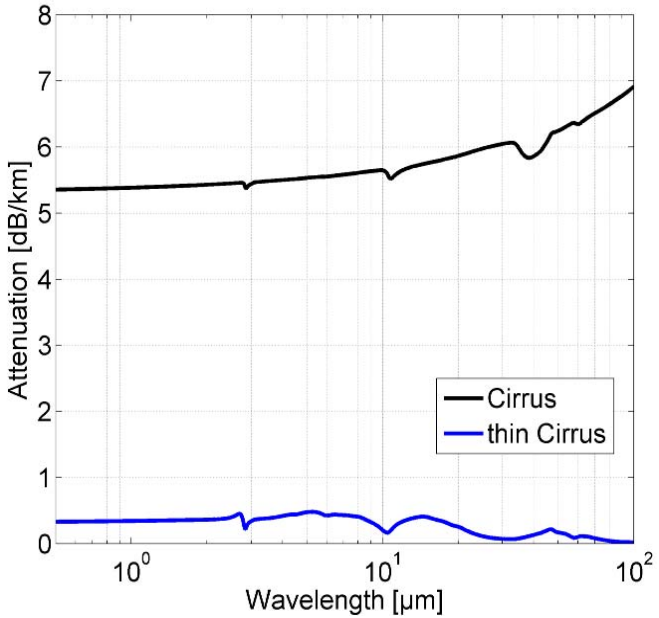




Attenuation in Clouds

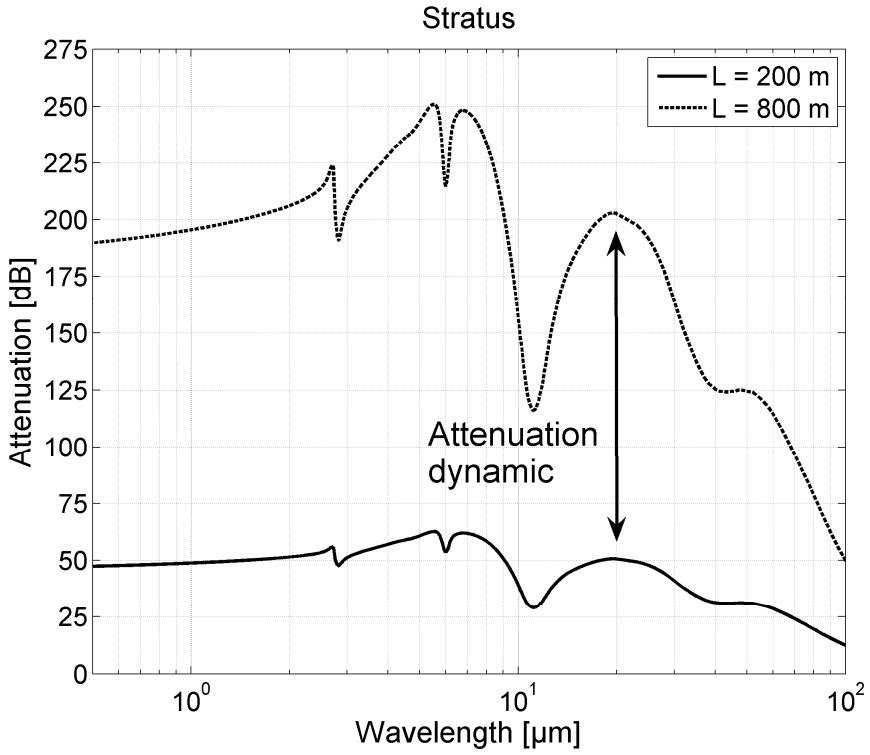
- High attenuation over the optical spectrum
- Minimization of cloud attenuation: Wavelengths between 10 and 12 µm

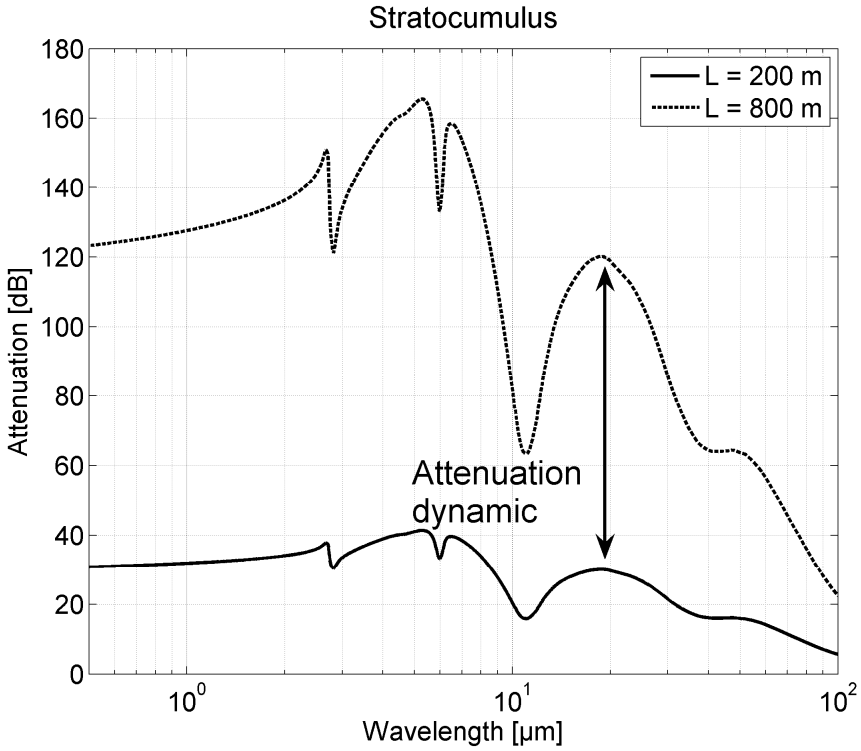




Attenuation in Clouds

- Total attenuation is calculated with the vertical extent
- Stratus and Stratocumulus have an extent of 200-800m





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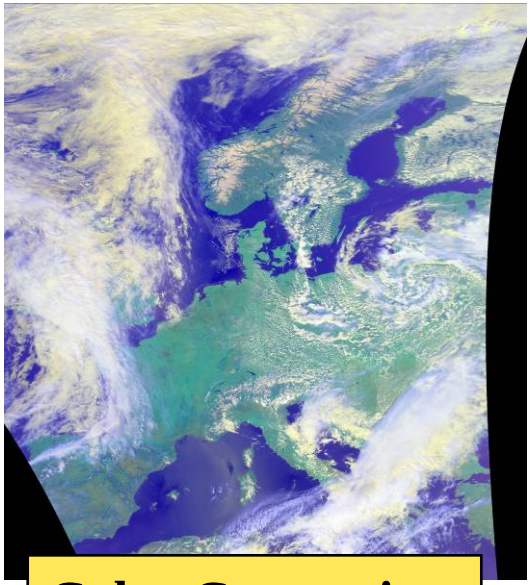
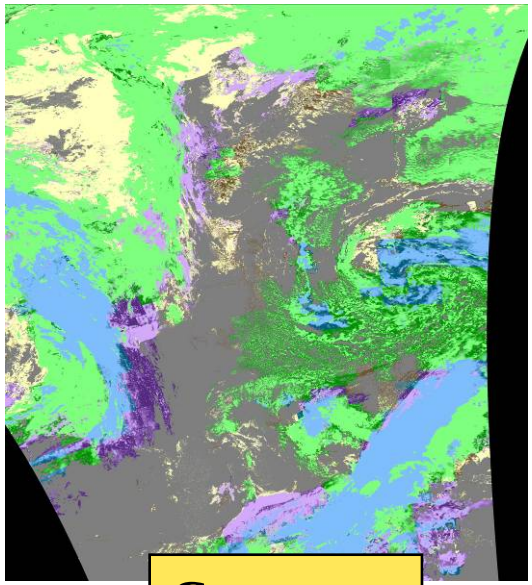
Link Availability Estimated from Earth Observation Products

- Different databases: MODIS, ECC, MSG, SYNOP, etc
- ECC-data chosen for current work
- Assumption: all cloud occurrence blocks the optical link (vertical)
- Five years of data regarded: 1990/1995/2000/2004/2005



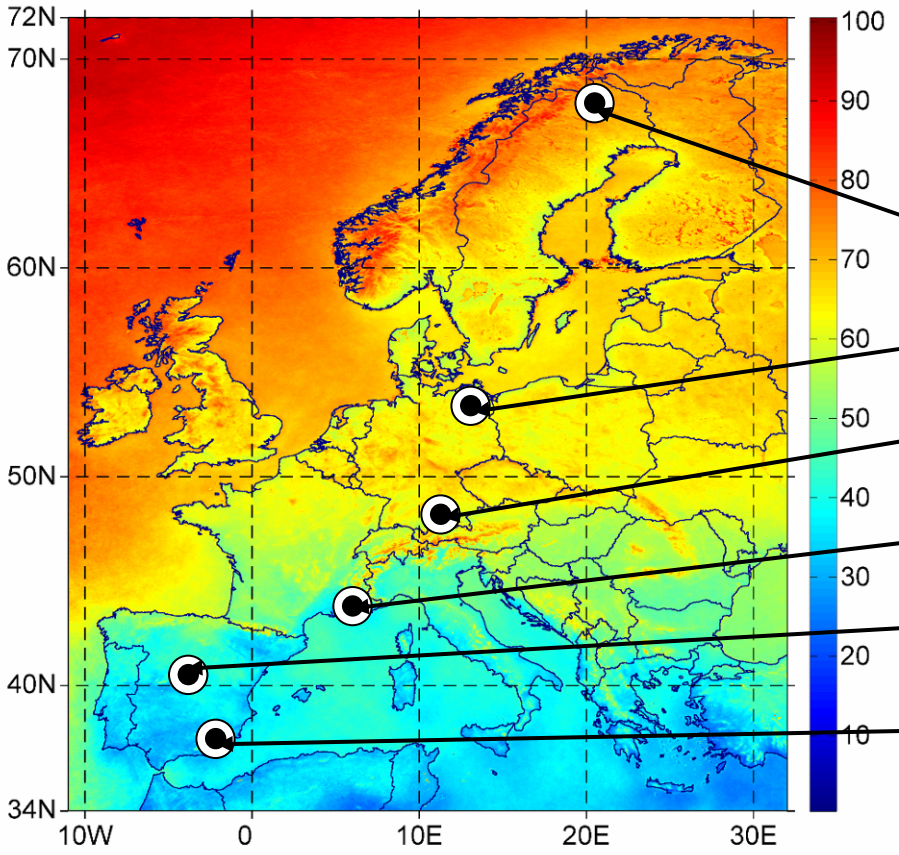
Color Composite



Coverage

Link Availability Estimated from Earth Observation Products

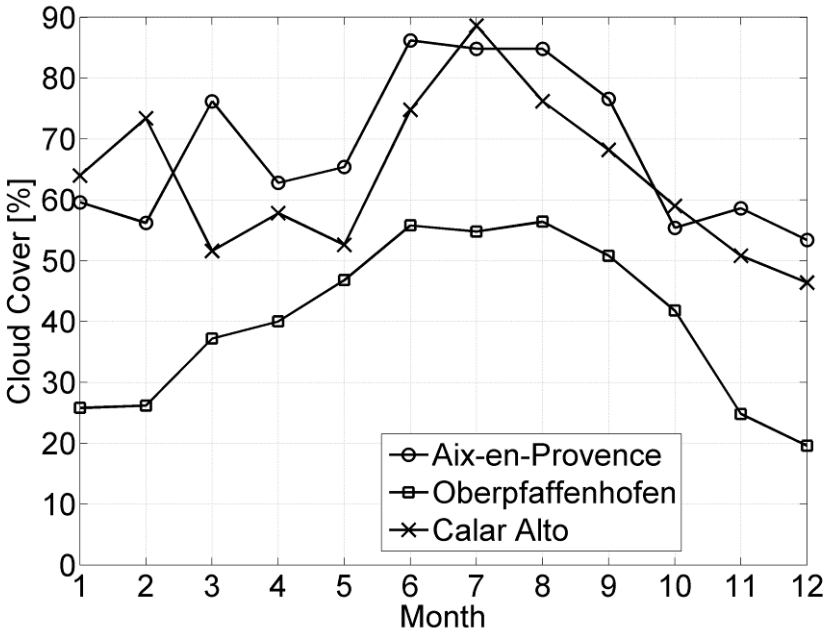
Mean cloud coverage over the year

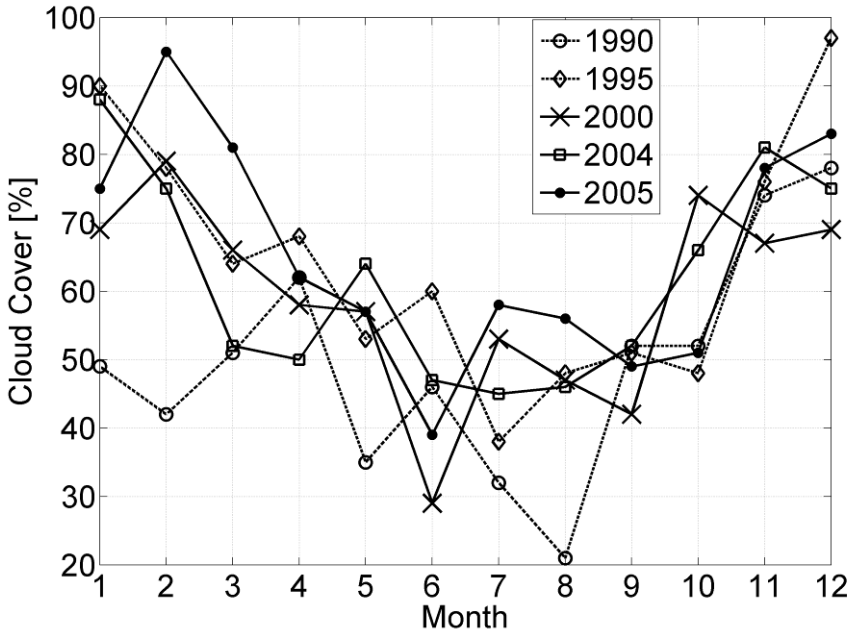


Location	Availability [%]	Std [%]
Kiruna (Sweden)	33	9
Neustrelitz (Germany)	37	4
Oberpfaffenhofen (Germany)	40	6
Aix-en-Provence (France)	68	5
Villafranca (Spain)	66	9
Calar Alto (Spain)	63	11

Link Availability Estimated from Earth Observation Products

- High dynamics between and in the years





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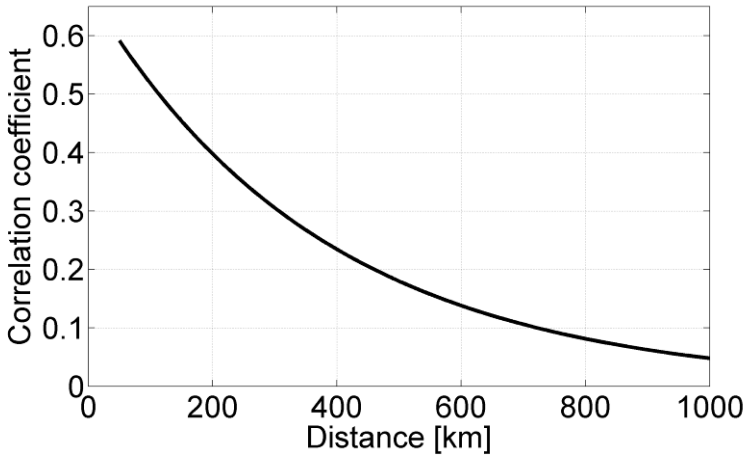
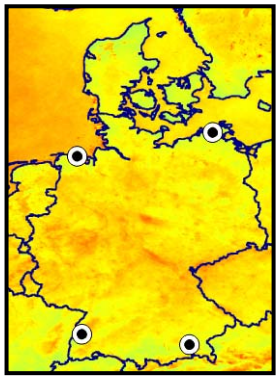
Link Availability Estimated from Earth Observation Products

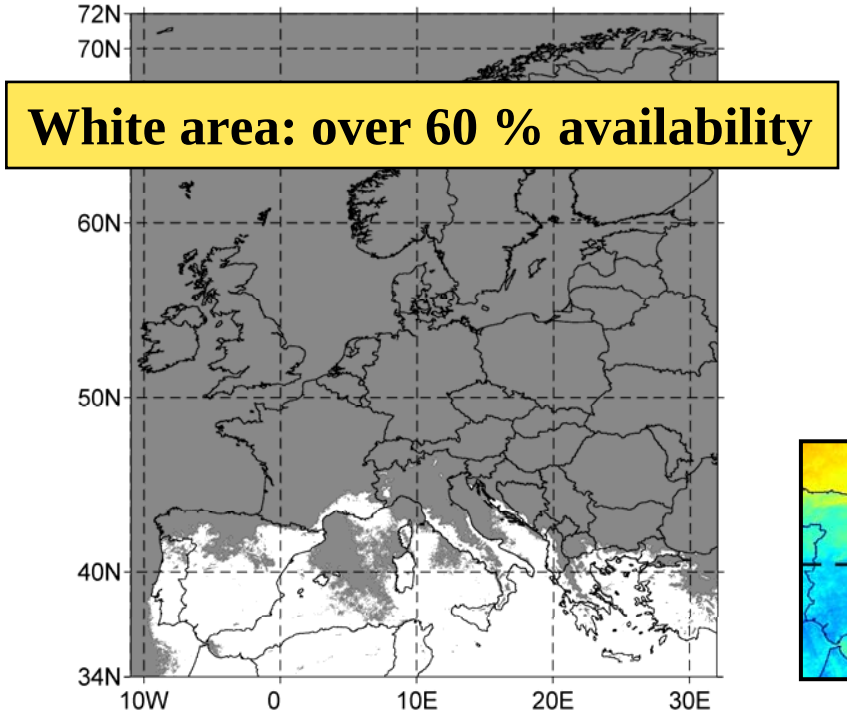
- Multiple Stations increase availability
- Distance between stations must be sufficiently long (>900 km) to have negligible correlation between weather cells
- If stations are closer correlation must be taken into account

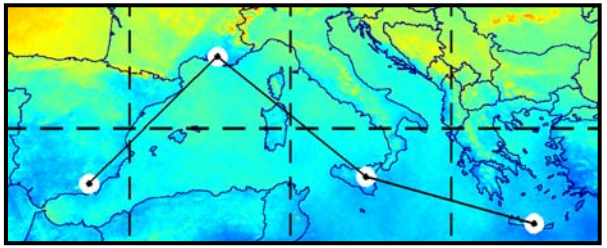
Fit of Correlation Coefficient



Link Availability Estimated from Earth Observation Products



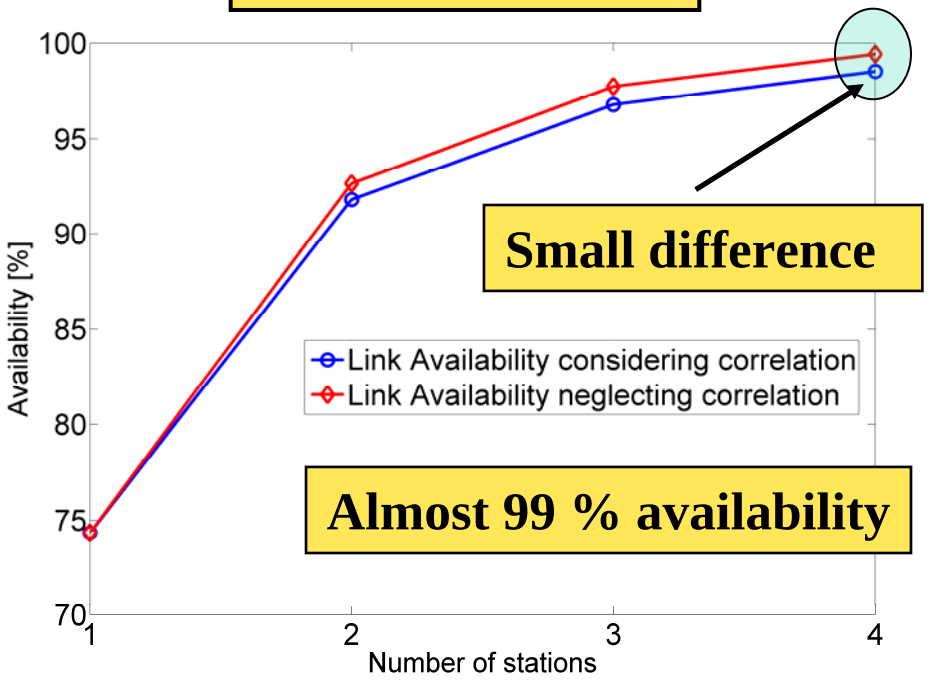




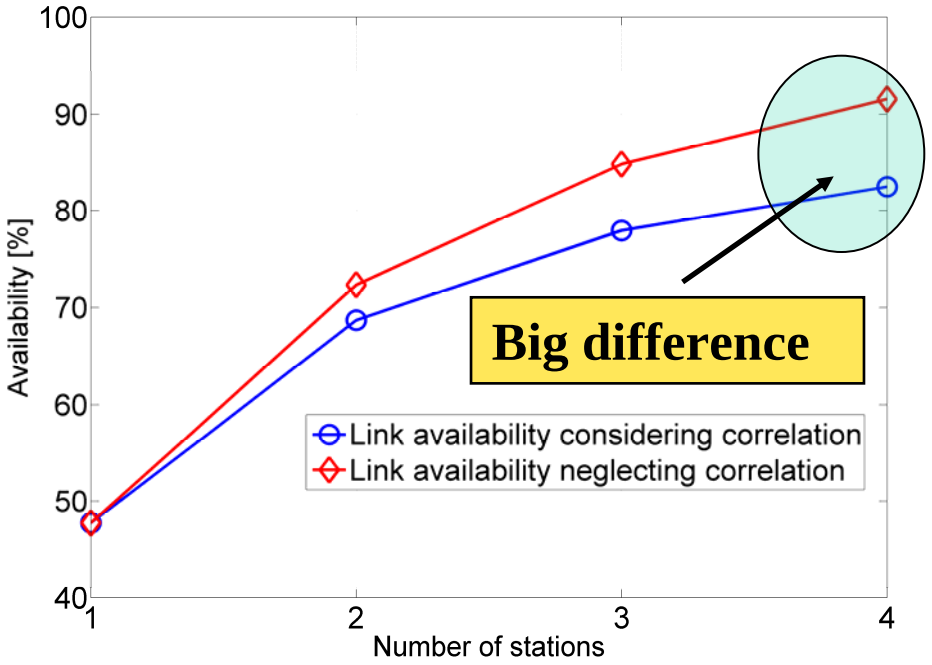
Availability of Ground Station Diversity Systems

- Comparison of two ground station diversity systems

System in Europe

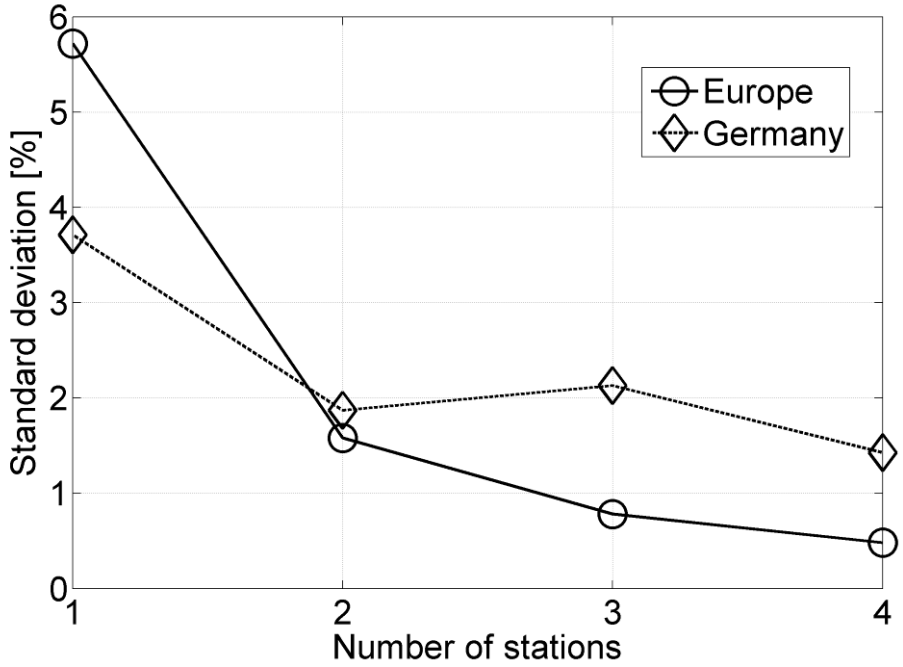


System in Germany



Availability of Ground Station Diversity Systems

- Comparison of two ground station diversity systems
- Decrease of variation → increase of reliability



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Conclusion and things to remember

- Wavelengths between 10 and 12 µm can be used for lower cloud attenuation
- Optical window VIII (7 – 15 µm) offers possibilities of use (CO_2-Laser, Quantum Cascade Lasers)
- ECC data makes it possible to estimate link availability in Europe
- Availabilities exceeding 65 % over the year can be reached with a single ground station in southern Europe
- An availability of almost 99 % can be reached with four ground stations in southern Europe
- When ground stations have large distances (>900 km) the correlation of weather cells is very low → negligible

What remains

- Statistics with larger database
- Comparison of statistics derived from different databases
- Calculation of ice cloud attenuation including realistic composition of non-spherical particles

Thank you very much for your attention…

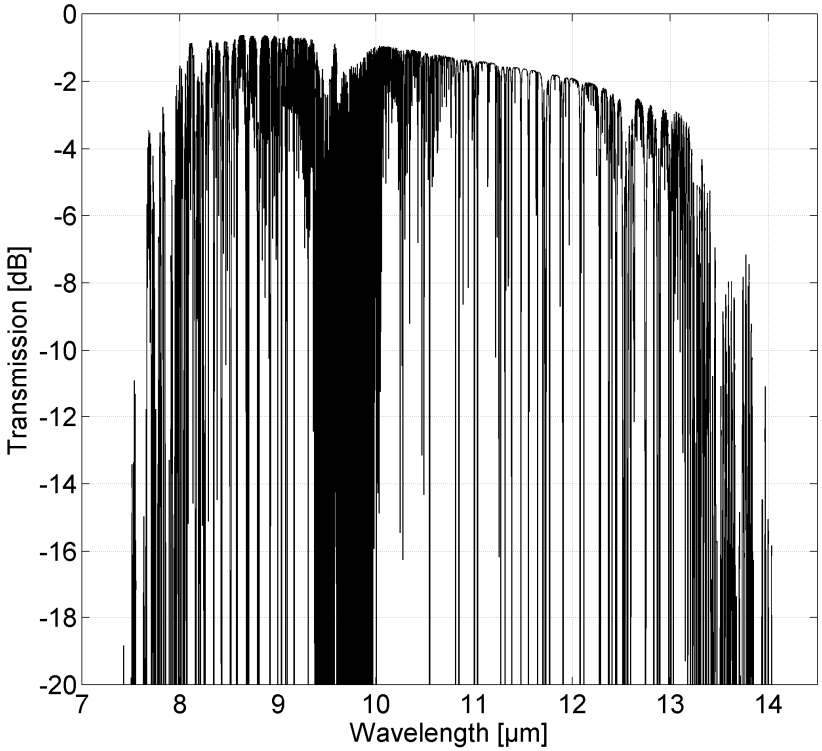
Examples of Stratocumulus species

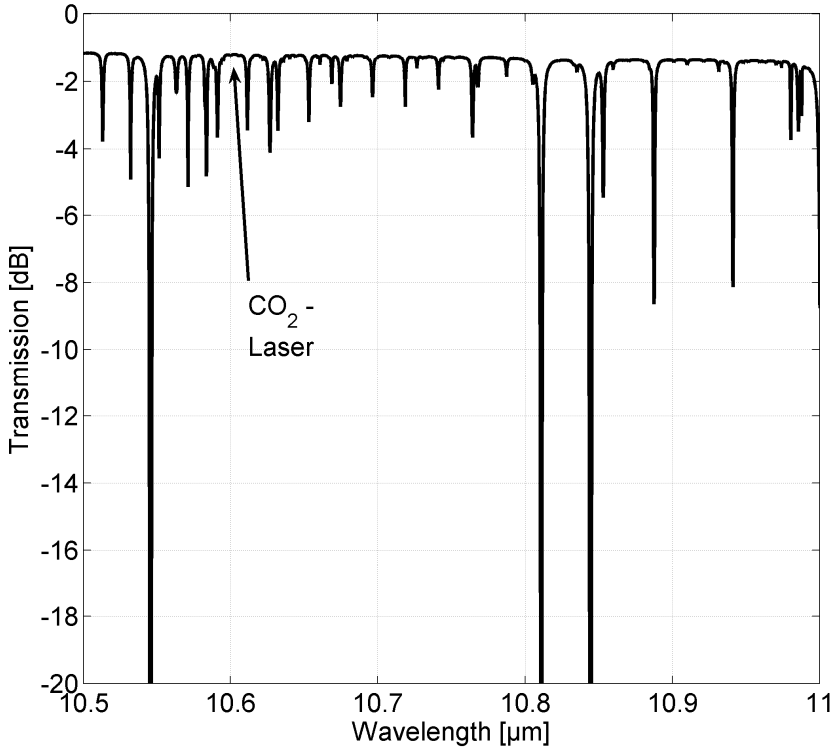
Examples of Stratus species

Examples of Cumulus species

Wavelength selection for better cloud transmission

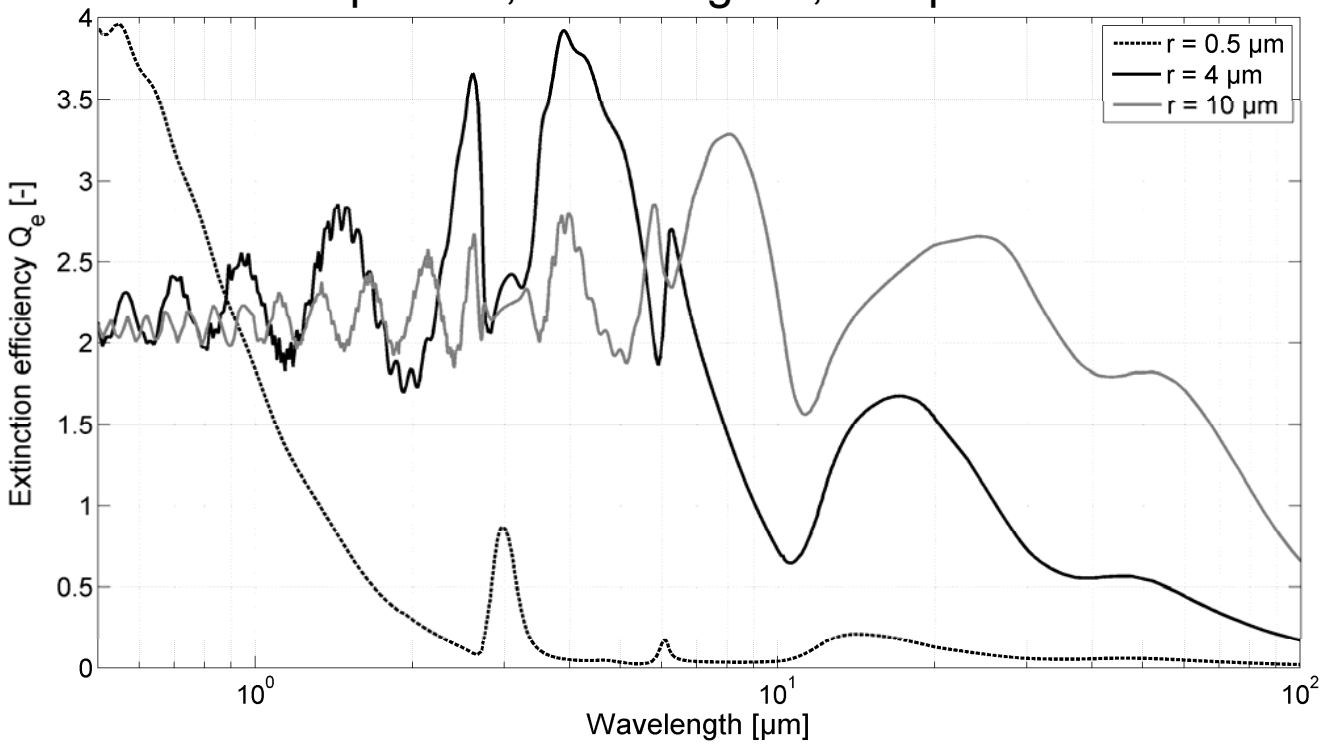
- High resolution calculation of molecular absorption is done with GENLN2, so all absorption lines are taken into account





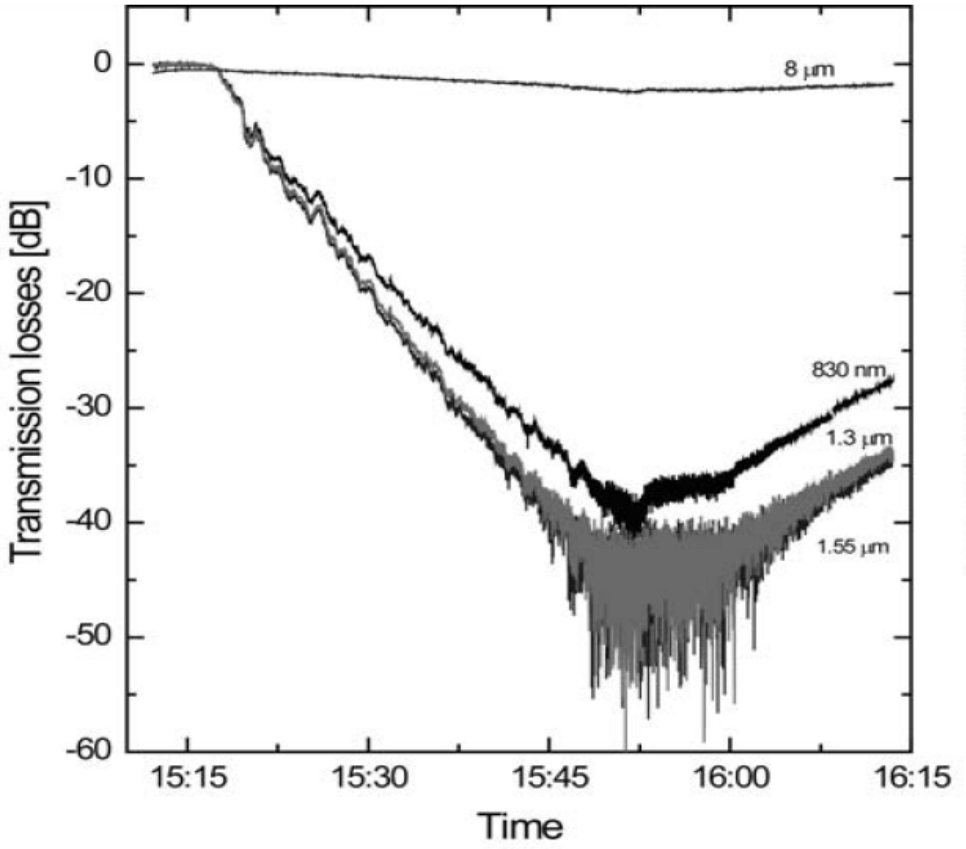
Cloud attenuation/ Mie scattering of spherical particles

- Theory of Mie calculates the Extinction Efficiency Q_e of a single spherical water drop
- Parameters: drop size *r*, wavelength λ, complex refractive index *n*



Attenuation in Clouds

Particle density



R. Martini (2005)

Cloud attenuation/ Cloud models

- Clouds are described with proper model
  - Particle size distribution (spherical shape)
  - Complex refractive index
  - Homogenous, not polluted

$$f(r) = a \cdot r^{\alpha} \cdot \exp(-b \cdot r^{\gamma})$$

- Particle size distribution $f(r)$ of Dermendjian
- Constants a, b, α, γ describe the cloud model
- Size distribution for Stratus and Stratocumulus cloud (right)